Study of Data Variability Acquired by Multiple Profilometers

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ABSTRACT: The accuracy and reliability of road monitoring data constitute a major concern among road designers, contractors and road administrations. These data may have foremost implications on rehabilitation strategies and, therefore, on costs and service life. For this reason, this paper aims to provide the interested bodies referred with useful information in relation to the variability of data acquired by road profilometers that is usually required. Five road profilometers, which belong to consultancy companies and research institutions, were used. Macrotexture and unevenness was measured on three selected road trials. Five runs were performed by each profilometer in both lanes of the road trials. The mean and the standard deviation were used to study the variability of the results. In relation to the macrotexture no significant differences were registered. For the unevenness the ratio between standard deviation and average MRI is higher than 20% and about twice the one found for macrotexture.

1 INTRODUCTION

Pavement surface irregularities, i.e. surface texture and unevenness, influence to a great extent factors such as safety (influenced by tyre/road friction), noise emission caused by tyre/road interaction, driving comfort, rolling resistance, wear of tyres and other operating costs.

According to ISO13473-1, the pavement texture is the deviation of a pavement surface from a true planar surface within the wavelength range of the microtexture, the macrotexture, the megatexture and the unevenness. The ranges of texture are defined as follows:

- microtexture: wave length below 0,5 mm; peak-to-peak amplitudes normally vary in the range of 0,001 mm to 0,5 mm;
- macrotexture: wave length between 0,5 and 50 mm; peak-to-peak amplitudes may normally vary in the range of 0,l to 20 mm;
- megatexture: wave length between 50 and 500 mm; peak-to-peak amplitudes normally vary in the range of 0,l to 50 mm;
- unevenness: wave length between 0,5 to 50 m.

Although unevenness is described by the amplitude and the wavelength, some authors do not consider it as a texture descriptor.

Pavement irregularities are currently surveyed at network level by high speed profilometers and the pavement condition is assessed through appropriate indicators related to macrotexture and unevenness, based on surface profiles. For these wave length ranges, there are standards which are widely used. For microtexture there are still some technical issues that are expected to be overcome shortly (Do et al., 2004) and for megatexture an EN standard is being worked out (Sjögren, 2008).

This paper is the result of the need to compare the irregularity indicators used by Portuguese public and private institutions that are currently involved in surveying pavement surface condition. Therefore, the objective of the work presented hereafter is the analysis of the variability of current irregularity indicators, which are the Mean Profile Depth (MPD), the Sensor Measured Texture Depth (SMTD) and the International Roughness Index (IRI).

2 IRREGULARITY INDICATORS

2.1 *Mean Profile Depth*

The MPD is calculated by dividing the measured profile into segments of 100 mm length (recommended base line). The slope of each segment is suppressed by subtracting a linear regression of the segment, providing a zero mean profile. The MPD is determined as shown in Figure 1. The MTD may be estimated through a conversion equation (also presented in Figure 1). In this case the MTD is indicated as Estimated Texture Depth (ETD).

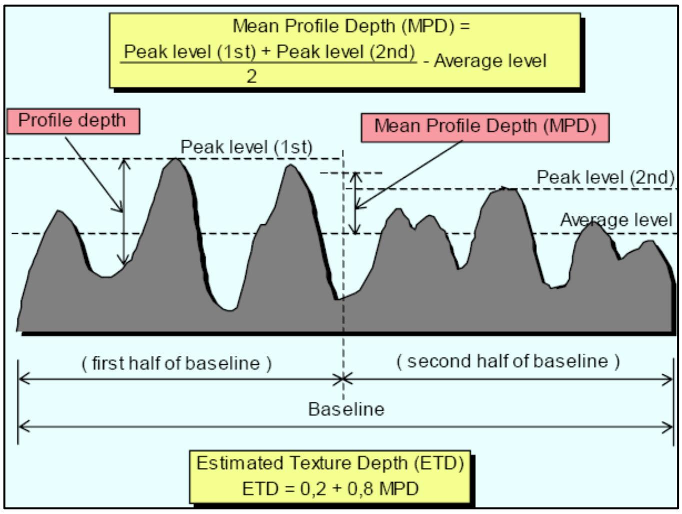


Figure 1. Illustration of the concepts of base line, profile depth and the texture indicators mean profile depth and estimated texture depth (in millimetres) (ISO 13473-1, 1997)

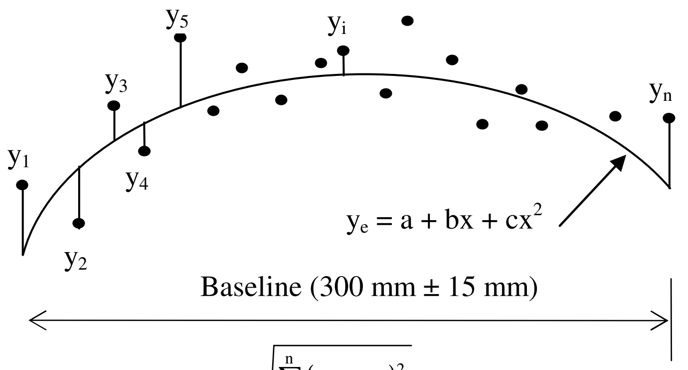
2.2 *Sensor Measured Texture Depth*

The Sensor Measured Texture Depth is the standard deviation of the profile amplitudes, measured by a sensor over a 300 mm ± 15 mm length of road. The effect of vehicle bounce is removed by applying a best-fit parabolic trend curve to the data obtained over the 300 mm length. The standard deviation is calculated using the deviations of the Texture Profile from the trend curve (Figure 3). These measurements are then averaged over lengths of 10 or 100 m.

2.3 *International Roughness Index*

The International Roughness Index (IRI) was developed by the World Bank in the 1980s (Sayers, 1986). IRI is an index computed from a longitudinal road profile measurement using a virtual response type system, quarter-car simulation (Figure 3) and running at a speed of 80 km/h. The simulation applied on the digitised road profile calculates the accumulated suspension motions divided by the distance travelled. The IRI has units of slope, e.g. mm/m or m/km. In the EN 13036 standard series the computation procedure for IRI is being dealt with, together with other longitudinal unevenness indexes (Sjögren, 2008). When the average IRI value of the left and right wheel tracks is calculated the corresponding index is referred to as the Mean Roughness Index (MRI).

IRI is considered to be a good indicator of pavement condition. It is widely used and a well established roughness index. It was developed in order to be linear, portable and stable with time. According to COST 354, it is portable since it can be measured with a wide range of equipment giving the same results. Likewise, it is stable with time once it is defined as a mathematical transformation of a measured profile. Thus it is neither affected by the measurement procedure nor by the characteristics of the vehicle used for profile measurement (COST 354, 2007).



$$SMTD = \sqrt{\frac{\sum_{i=1}^{n}(y_i - y_e)^2}{n}}$$

Legend:
SMTD = Sensor Measured Texture Depth
yi = laser height measurement at laser measurement i
n = number of laser measurements (odd)
y_e = curve obtained by quadratic least square regression
x = distance between measurements
a, b, c = curve parameters

Figure 2. Illustration of concepts related to the procedure calculation of the SMTD

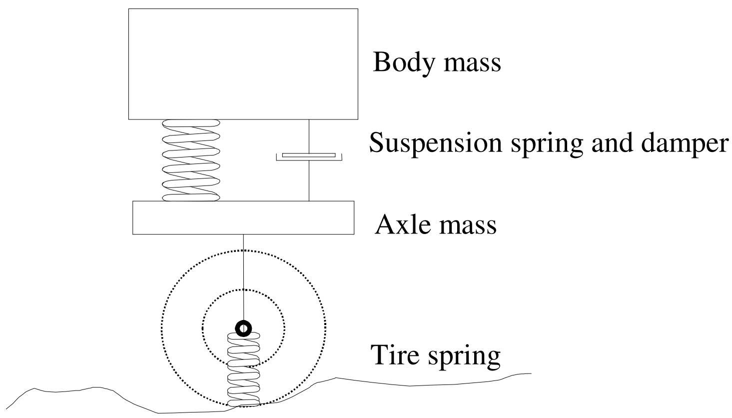


Figure 3. Quarter car model for IRI

2.4 *Data variability*

Data variability is influenced by several sources, such as: equipment instability; software imperfections; operator influence; surface longitudinal inhomogeneity; surface lateral inhomogeneity (difficulty of measuring in the same lateral track each time). Surface longitudinal and lateral inhomogeneities generally dominate the repeatability of results, while the other sources may also have an important contribution to their reproducibility.

Data variability analysis may be carried out through simple statistical parameters such as variance, standard deviation, range and coefficient of variation.

Specifically for profiling devices it is important to study repeatability and reproducibility. On the one hand, repeatability is understood as the capability of a device to reproduce the same result in multiple runs. It is generally expressed as the average and the standard deviation for data from repeated runs. On the other hand, reproducibility refers to the closeness of the results reported by different devices under the same measurement conditions. It is characterized by the standard deviations of the values reported by different teams for a given index. It includes the standard deviations for the repeatability as well as the standard deviation for interdevice variability.

The PIARC International Experiment (Wambold et al., 1995) shows that ETD can be determined for a 150 m test section with a standard uncertainty of approximately 20 % of the average value. The reproducibility, which also includes the effect of the repeatability, using two different systems and test crews, was found to be 0.15 mm in the same experiment, corresponding to 10 % of the average texture depth in the experiment (residual error in regression between two devices). lf more or longer runs are made over the same test section, the uncertainty decreases according to conventional statistical procedures when averaging random data.

For the IRI, typical variations in lateral positioning may cause repeat measurements to vary up to 20% on a section of 300 m long (Karamihas, 1999). In the EVEN Project, for the twenty US test sections, the standard deviation of the IRI ranged from 0.09 to 0.28 m/km. For the seventeen Japanese test sections the standard deviation ranged from 0.20 to 0.55 m/km (Schmidt, 2001).

3 EXPERIMENTAL PROCEDURE

3.1 *Test methodology*

In order to carry out the analysis of the variability of data, three surface layers with low, medium and high texture depth were chosen among the most widely ones used in Portugal, located along a motorway and along a national road. They are made of dense asphalt (DA), gap graded asphalt known as “open texture asphalt” (OTA) and porous asphalt (PA). For each type of surface two sections, one for each road direction, were tested:

- PA – sections 1 and 3 with a length of 7 km;
- OTA – sections 2 and 4 with a length of 18 km;
- DA – sections 5 and 6 with a length of 1.5 km.

For the analysis MPD, SMTD and IRI calculated based on surface profiles, five runs were made at traffic speeds by five profilometers over the six test sections.

The data registered every 10 m were position, speed, MPD or SMTD on the right wheel path and profile singularities. For the IRI, the data were registered every 100 m in both wheel paths.

3.2 *Profilometers*

The profilometers used during the tests belong to universities, research laboratories and consultancy companies (Figure 4). For the measurement of the longitudinal profile an accelerometer which is used to obtain the vertical movement of the vehicle body, and a laser sensor which is used for measuring the displacement between the vehicle body and the pavement were installed in the vehicles. Road profile measurements are obtained by summing the body movement with the with the appropriated body-road displacements.

Figure 4. Testing profilometers

The measured longitudinal profiles meet the Class 1 precision and bias specifications as defined by ASTM E-950.

IRI is calculated according with the World Bank Specifications. The texture is calculated as explained above. All profilometers can provide IRI. The MPD is provided by profilometers equipped with 60 kHz lasers (referred as PER1, PER2 and PER3) and SMTD provided by profilometers equipped with digital 16 kHz lasers (PER 4 and PER 5).

4 ANALYSIS OF THE RESULTS OF HIGH SPEED PROFILOMETERS

This experiment was carried out under normal operation conditions, on dry weather. The data recorded was used as provided by each operator and possible outlier values were included. Therefore, all possible sources of error are included and will be reflected in the repeatability and the reproducibility of the methods under analysis.

4.1 *Mean Profile Depth*

Figures 5 and 6 depict the average and the standard deviation of the MPD calculated for each run of the three profilometers that provide this indicator in the six test sections. Sections 5 and 6 were not surveyed by PER3 for operational reasons.

The results presented in Figures 5 and 6 show that the three equipments that evaluated MPD provide results of the same order of magnitude, both in terms of average over the whole section and in terms of standard deviation.

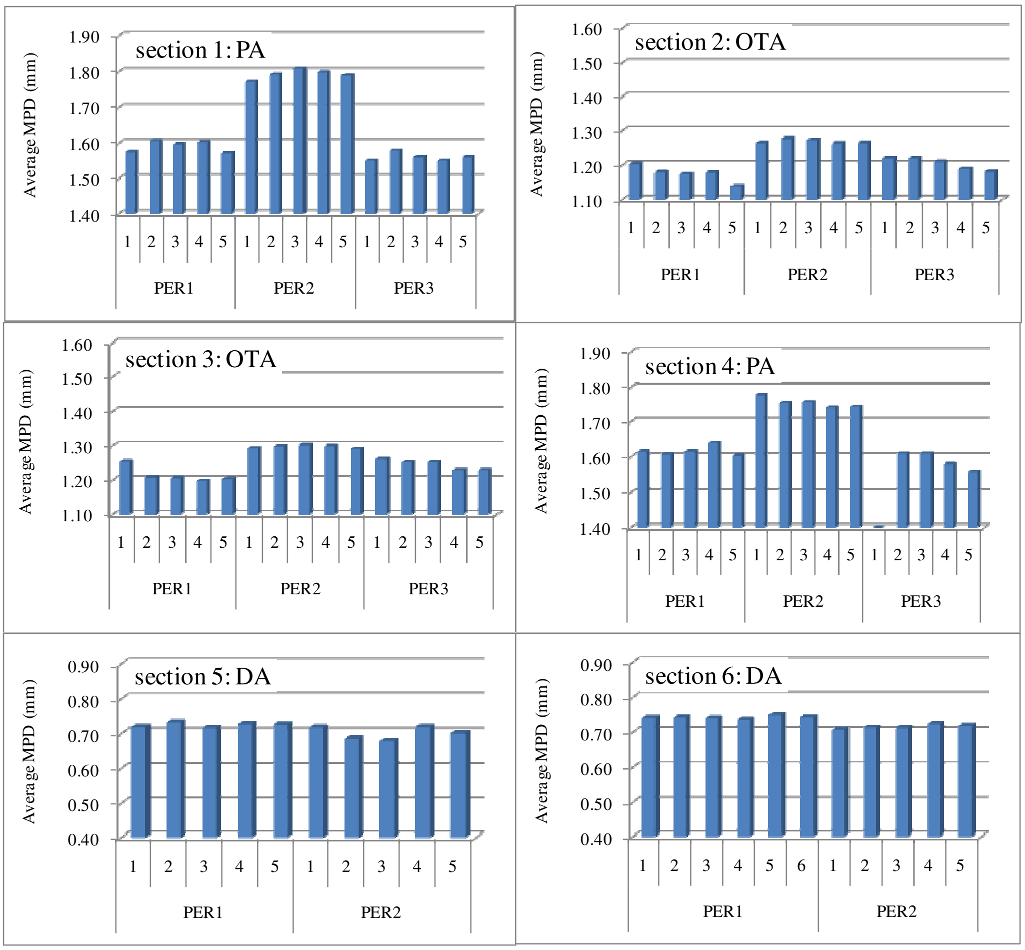


Figure 5. Average MPD

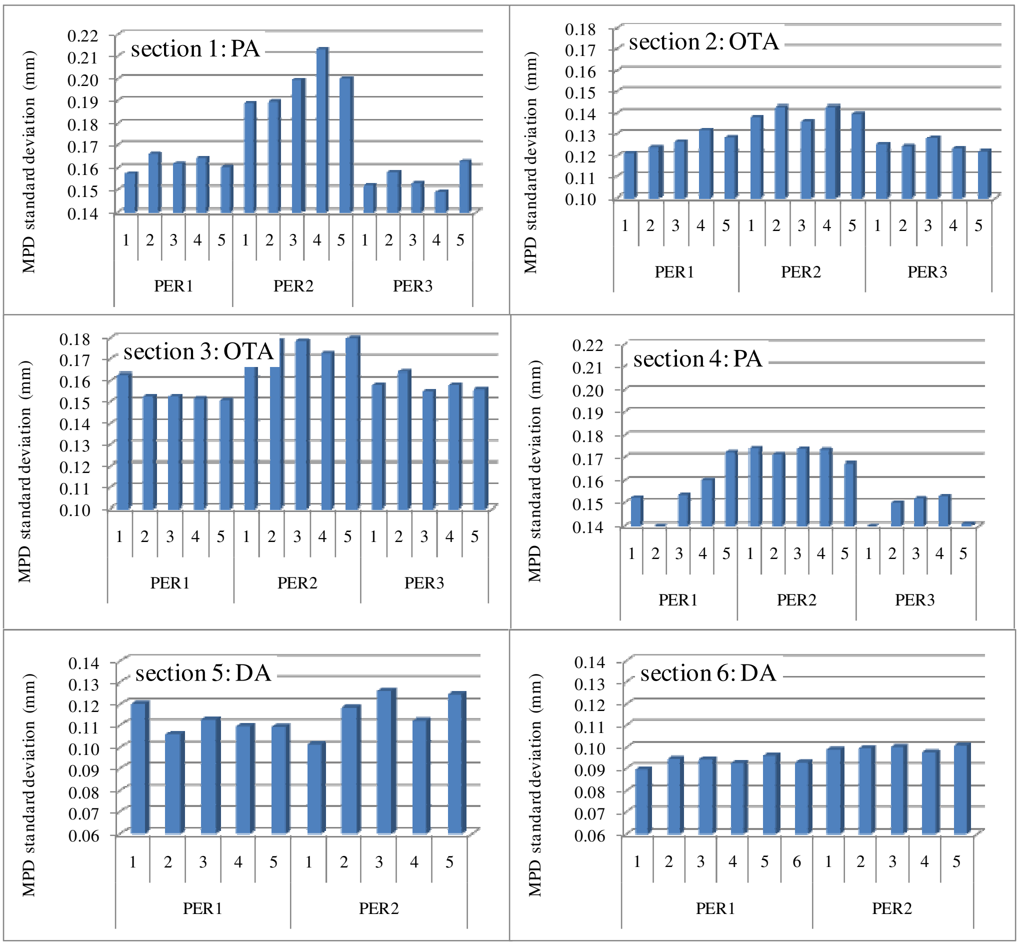


Figure 6. Standard deviation of the MPD

Furthermore, the following observations were made:

- For each equipment, and for the three types of surfaces, the average MPD has negligible variations among different runs;
- The equipment PER 2 tends to provide higher values of MPD for the higher texture surfaces. For the dense asphalt the difference between devices is smaller;
- For higher texture depths (porous asphalt and "open texture asphalt"), the standard deviations obtained with any equipment on any run is less that 10% the average value. For dense asphalt, the ratio between the standard deviation and the average is slightly higher than 10%.

4.2 *Sensor Measured Texture Depth*

The same analysis procedure was used for the SMTD. Profilometer number 5 ran 4 times instead of 5 in sections 1 to 4. The results are presented in Figures 7 and 8.

In general, the average SMTD and the standard deviation are fairly similar either for the same profilometer or between profilometers. However, the following statements can be made:

- The average SMTD and the standard deviation for PER4 are slightly higher than for PER5. In practical terms those differences can be neglected;
- For each profilometer, the similarity of the average SMTD among runs is better for dense asphalt which has low texture depth;
- The ratio between standard deviation and average values becomes higher with the increase of SMTD average. It means that the higher texture depths the higher variability of the results.

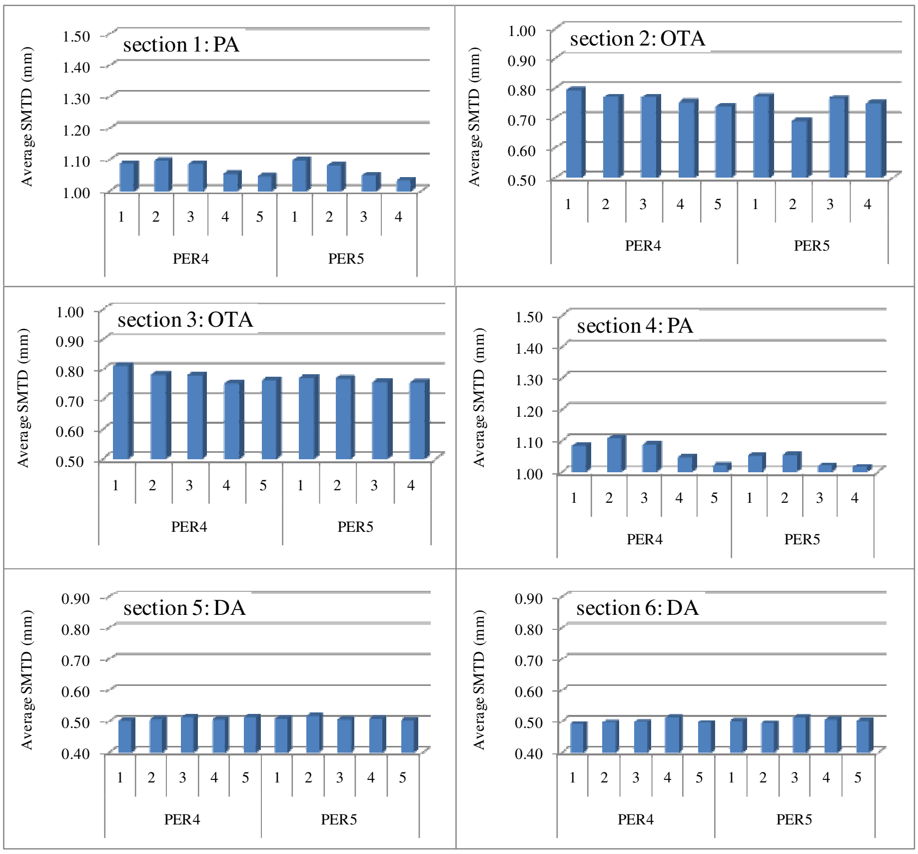


Figure 7. Average SMTD

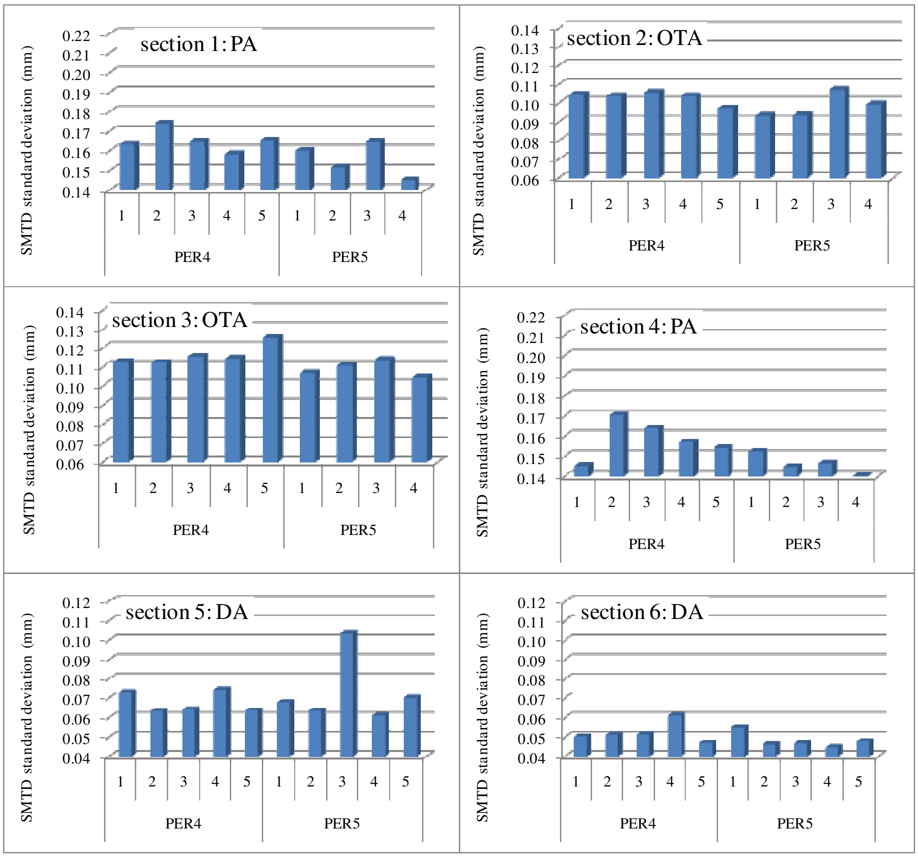


Figure 8. Average Standard deviation of the SMTD

4.3 *International Roughness Index*

For the analysis of the variability of the IRI, the average of the results of the left and the right wheel paths, which provide the MRI, was used. Figures 9 and 10 show correspondingly the average MRI and the standard deviation acquired by all profilometers in the six test sections.

For each equipment, and for all types of surfaces, the average MRI has negligible variations among different runs.

The equipment PER 4 tends to provide higher values of MRI. For the DA the difference between devices is considerably higher than for PA and OTA, nevertheless the difference is smaller than 0.3 m/km.

For the standard deviation, values between 0.10 and 0.60 were found. A much higher standard deviation in the third run of PER5 was calculated. This result was influenced by a 100 m subsection which should be discarded from the analysis as it seems to be an outlier. These results are according to the ones published in the FILTER experiment.

The standard deviations obtained with any equipment on any run are 20 to 30% the average value. For the dense asphalt section, the ratio between the standard deviation and the average values is generally higher than for the other sections. This is probably due to the fact that the PA and OTA sections were located on a motorway, where the specifications for surface evenness of newly built pavements may be tighter. In the case of the OTA section, the ratios between the standard deviation and the average values are more than twice the equivalent ratios found for the texture depth.

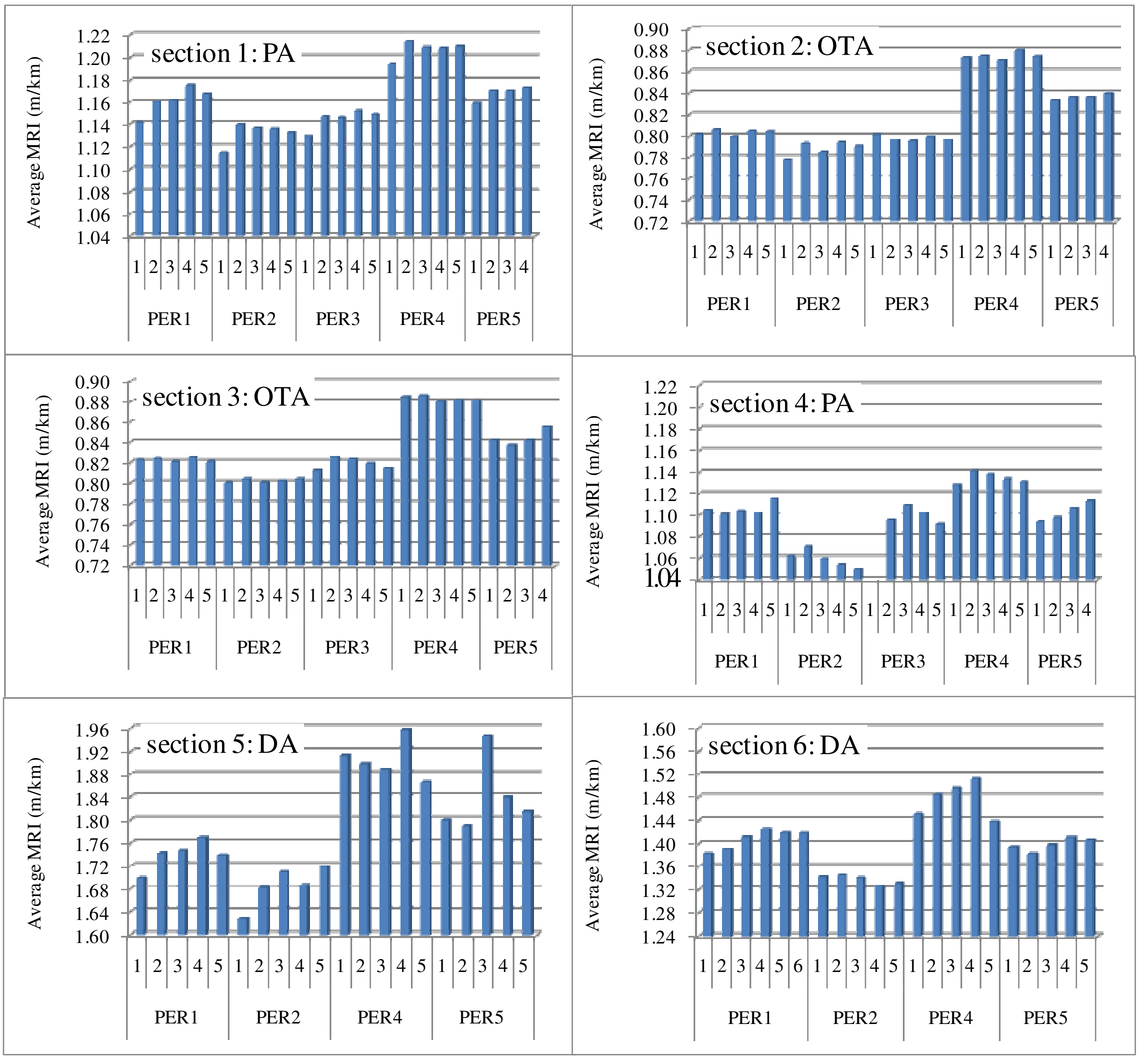


Figure 9. Average MRI

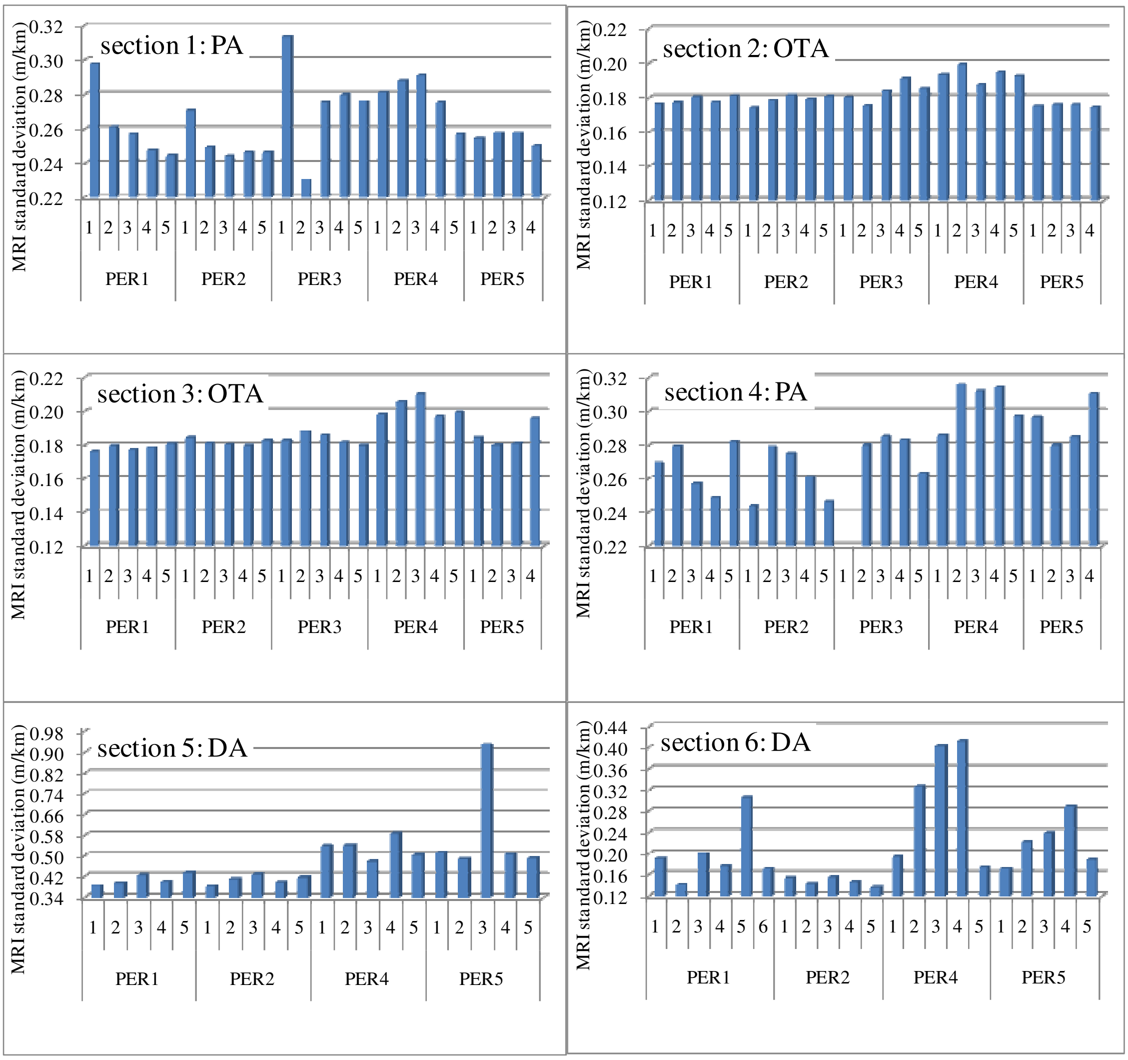


Figure 10. Standard deviation of the MRI

5 CONCLUSIONS

The functional quality of pavements is irrefutably influenced by surface irregularities. For this reason, parameters such as macrotexture and unevenness, which are derived from surface irregularities at certain wavelength ranges, are currently monitored at network level. Since different devices provide different results, it is important to perform an analysis of the variability of the results derived from the use of different devices. For this purpose, a study based on the analysis of the mean and the standard deviation of the most used irregularity indicators was performed in Portugal. These indicators were the Mean Profile Depth (MPD), the Sensor Measured Texture Depth (SMTD) and the International Roughness Index (IRI). The tests were carried out under ordinary testing conditions on three types of surfaces: porous asphalt, “open texture asphalt” and dense asphalt.

The following main conclusions may be reported:

- For each equipment, and for the three types of surfaces, the average MPD has negligible variations among the different runs;
- The comparison between different high speed equipments that provide the same type of indicator (either MPD or SMTD) indicates that they provide similar results, both in terms of average and in terms of standard deviation, although there are slight differences between them;

- In terms of average IRI there is one specific equipment which provides slightly higher values. These differences are more significant in one particular section;
- The ratio obtained between standard deviation and average MRI is 20 to 30%, for any equipment on any run. This ratio is about twice the one obtained for the macrotexture.

Finally, it is recommended that this type of experiment is repeated in order to broaden the experience to other types of surfaces, with different ages and under different conditions.

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